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APPLICATION NOTE

AN980

VHF Narrowband FM Receiver Design Using the MC3362 and the MC3363 Dual Conversion Receivers

Prepared by: Jon Stilwell
              Ricky Ng

Motorola has developed a series of low power narrowband FM dual conversion receivers in monolithic silicon integrated circuits. The MC3362 and the MC3363 are manufactured in Motorola's MOSAIC process technology. This process develops NPN transistors with $f_T = 4 +$ GHz, which allows the MC3362 and the MC3363 to have excellent very high frequency (VHF) operation with low power drain. They are ideal for application in cordless phones, narrowband voice and data receivers, CB and amateur band radios, radio frequency (RF) security devices and other applications through 200 MHz.

Features of the MC3362/3 Receiver ICs:
● Broadband RF input frequency capability (to 200 MHz using internal oscillator, over 450 MHz using external oscillator)
● Single supply operation from $V_{CC} = 2$ to 7 Vdc
● Low power consumption ($I_{CC} = 3$ mA typical at $V_{CC} = 2$ Vdc)
● Internally biased NPN RF transistor amplifier (MC3363)
● Complete dual conversion circuitry — first mixer and oscillator included
● First local oscillator (LO) includes buffered output and varactor diode to allow phase locked-loop (PLL) frequency synthesis for multichannel operation.
● Buffered second local oscillator output available for PLL reference input (MC3362)
● Multistage limiter and quadrature detection circuitry included
● RSSI (Received Signal Strength Indicator) with Carrier Detect logic included
● Built-in data slicing comparator detects zero crossings of FSK data transmission
● Inverting operational amplifier included for audio muting or active filtering (MC3363)

SCOPE

This application note contains functional descriptions and applications information pertaining to the various functional blocks of the MC3362/3 receiver circuits. Four receiver application circuits are shown. A single channel receiver and a 10 channel frequency synthesized receiver

designed for the 49 MHz cordless telephone band are shown. A 256 channel "2 Meter" (144–148 MHz) amateur band receiver is also shown, including an appropriate PLL frequency synthesizer design to control the receiver's local oscillator. Finally, a low cost application featuring the MC3362 as a single chip manually tunable 162 MHz weatherband receiver is shown. A directory of external component manufacturers is included as an appendix.

COMPARISON OF THE MC3362 AND THE MC3363

Figures 1A and 1B show the system block diagrams of MC3362 and MC3363, respectively. The MC3362 and the MC3363 are made from the same die, but a final metal mask difference allows different features to be made available on each. Data pertaining to the common functional blocks are identical on both circuits.

The MC3363 is a complete VHF dual conversion FM receiver including RF amplifier, two mixers and oscillators, limiting IF amplifier and quadrature detection circuitry, received signal strength indicator (RSSI) circuitry, squelch circuitry and a data shaping comparator for detecting FM frequency shift keyed (FSK) data transmissions. Receivers using the MC3363 alone can achieve better than 0.3 μV input sensitivity for 12 dB SINAD, from a 50 Ω source. The MC3363 comes in a 28-lead plastic wide SOIC package only.

The MC3362 is optimized for cordless telephone applications and as such does not contain the RF preamplifier or squelch circuitry. In addition, the second local oscillator contains a buffered output so that it can serve as the system frequency reference in applications where a 10.240 MHz or 10.245 MHz reference is needed. In general, the MC3362 can be substituted for the MC3363 where:

● A receiver with sensitivity of 0.7 μV at the input for 12 dB SINAD is adequate.
● An external RF preamplifier with AGC is desired (such as MOSFET's 3N211 and MPF211).
● Receiver squelch is not needed.
● Surface mount technology cannot be used. The MC3362 is available in two 24-lead plastic packages (DIP and wide SOIC surface mount).
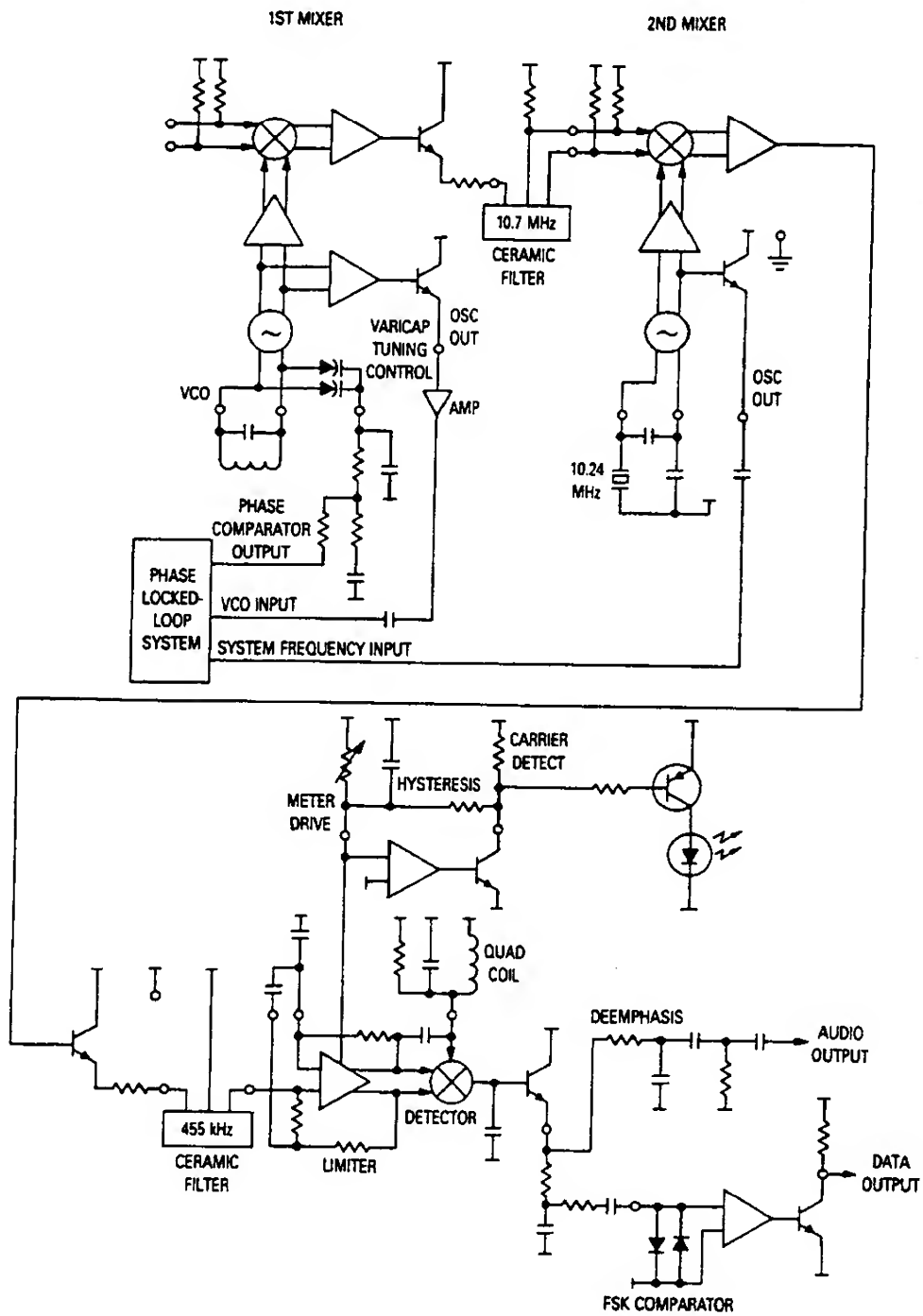
MOSAIC is a trademark of Motorola, Inc.

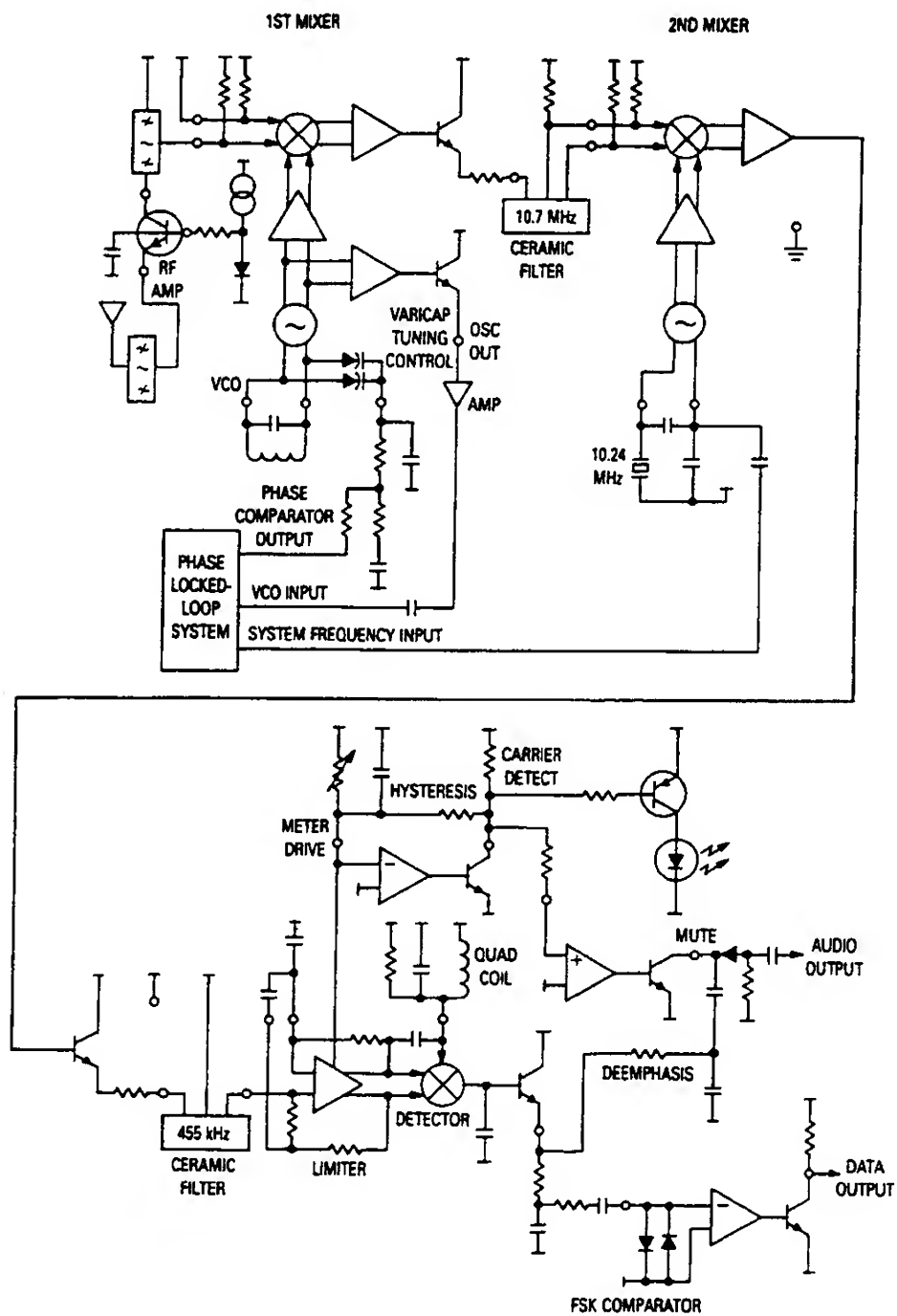Ⓜ *MOTOROLA* ■

Figure 1A. MC3362 Internal Block Diagram

Figure 1B. MC3363 Internal Block Diagram

FEDERAL REGULATIONS, RECOMMENDED STANDARDS

Radios built for certain VHF and UHF bands may qualify under the FCC Code of Federal Regulations Title 47, Part 15, for use by unlicensed operators. It is important to know the federal regulations concerning a particular frequency channel or band of channels before a receiver or transmitter circuit is designed. **Contact the FCC/Government Printing Office to order a copy of the Code of Federal Regulations, Title 47, Parts 0–20 which contains Part 15, before designing a radio receiver or transmitter for unlicensed utility applications.**

Professional (landmobile) radios come under another part (Part 90) of the Title 47 code. There are a set of standards, published by the Electronic Industries Association, which dictate recommended operating specifications for two way communication equipment. These standards provide useful information about radio performance, terminology and measurement techniques and are useful even if professional radios are not a designer's primary goal. Contact the EIA at (202) 457-4900 to order the standards listed below. The FCC/GPO can be reached at (202) 275-2054 or (213) 894-5841. The pertinent documents are:

Number	Description	Parts Referenced
FCC Title 47, Part 15	Code of Federal Regulations	Radio Frequency Devices
FCC Title 47, Part 90	Code of Federal Regulations	Landmobile Radios
RS-204-C	EIA Recommended Standard	FM/PM Receiver Standards
EIA-152-B	EIA Recommended Standard	FM/PM Transmitter Standards
EIA-316-B	EIA Recommended Standard	Test Conditions, Radio Standards

REFERENCE LITERATURE

The following Motorola literature may be useful when designing with the MC3362/3 receivers:

Number	Description	Parts Referenced
DL128, Rev. 2	Linear and Interface Device Data	MC3362, MC3363, MC34119, MC2831A, MC2833, MC13060, MC33171
DL130	CMOS/NMOS Special Functions Data	MC1451XX CMOS PLL's
DL122	MECL Device Data	MC12XXX ECL Prescalers
DL126	Small Signal Transistor Data	3N211, MPF211

COMPANION DEVICES

- The MC2831A and the MC2833 low power FM transmitter ICs provide all essential functions for cordless telephone and general transmitter and oscillator applications through 60 MHz (MC2831A) and 200 MHz (MC2833, using internal very high frequency [VHF] transistors as frequency multipliers).
- The MC34119 low power audio amplifier with differential outputs provides efficient power transfer and eliminates the need for the typical large audio coupling capacitor.
- The MC13060 Mini-Watt audio amplifier (for higher powered audio output).
- The MC33171 low power single supply operational amplifier for use as an RSSI buffer or active integrator.
- The MC14516X series of dual PLL frequency synthesizers for development of 10 channel cordless telephone band transceivers.
- The MC12XXX series of ECL prescalers and
- MC1451XX series of CMOS Frequency Synthesizers for development of VHF "high band" radios to 200 MHz
- The MC145442/3 single chip 300 baud modems which allow audio frequency shift keyed (AFSK) RF modem design for very reliable data transmission.
- The 3N211 and MPF211 dual gate MOSFET's for MC3362 RF preamplification with AGC capability.

BLOCK DESCRIPTION

RF Amplifier (MC3363 only)

The MC3363 contains an internal NPN bipolar RF amplifier transistor. The base of the transistor is biased internally to approximately 0.8 Vdc, which simplifies common-emitter amplifier design. Grounding the emitter yields an emitter current I_E = 1.5 mA and voltage gain A_V = 20 dB with a collector load R_L = 1 kΩ.

Emitter degeneration resistors can be added to lower current drain, with R_E decoupling used to preserve the gain. With the emitter grounded the input at Pin 2 looks like 180 Ω in parallel with 20 pF at 50 MHz. The noise figure at 50 MHz and unity gain frequency (f_T) of the NPN transistor are approximately 2 dB and 3 GHz, respectively, at I_E = 1.5 mA. The collector load can be resistive, as shown in Figure 10, or tuned as shown in Figure 14. When both input and output are tuned and/or impedance matched care must be taken to prevent unwanted oscillations — this is why the 2 kΩ resistor is included in the collector load of Figure 14.

First Mixer

The first mixer is a doubly balanced multiplier, driven directly from the RF input and from the first local oscillator via a cascode amplifier. It is used to convert the RF input frequency down to the first IF of 10.7 MHz. The input admittance seen at either RF input pin is 670 ohms in parallel with 7 pF at 50 MHz; that is, Rp = 670 Ω and Cp = 7 pF. The series equivalent impedance at 50 MHz is Rs = 210 Ω and Cs = 10.2 pF. The first mixer's input is differential, but can be driven single-ended with no loss in system gain. If a single-ended input is used, be sure to AC ground the unused pin. This can be done with a bypass capacitor to the negative rail (V_{EE}) or by connecting the pin directly to the V_{CC} supply.

The isolation of the mixer is shown in Table 1, and of particular value in many applications will be the strong attenuation (41 dB) of the local oscillator at the mixer input. The isolation is due to the fully balanced mixer configuration used and helps to reduce LO radiation at the receiver's antenna.

Table 1. First Mixer Isolation Level (in dB) at:

Signal	LO Tank	Mixer Out (IF)	Mixer In (RF)
LO	0	−17	−41
RF	−16	−9	0
IF	−29	0	< −40

Initial Alignment of LC Tank	Final Configuration

NOTES:

1. The varactor control pin controls the net capacitance across the local oscillator tank pins. The net capacitance will be approximately 20–25 pF when this pin is left open and 10–15 pF when connected to V_{CC}, depending upon strays and the V_{CC} value used. If the V_{CC} supply is regulated, connect the varactor control pin to V_{CC}; otherwise, bypass via a 0.01 μF capacitor to ground.

2. Connect the oscillator as shown in the left hand drawing (Initial Alignment) and adjust L1 so that the tank resonates approximately 2–3 MHz below the crystal frequency. The frequency should be checked by examining the buffered output using a high impedance probe or by some sort of inductive pickup which will not push the oscillator off frequency. The frequency should be:

$$f_{LO} \approx \frac{1}{2\pi \sqrt{(L1 + L2)} \, C_{varactor}}$$

3. Break the L1–L2 connection and add X1 and R2. Verify that the LO operates at the desired frequency by applying an RF input of

10.7 MHz above or below the crystal frequency and checking for receiver quieting. Make sure that there is proper LO amplitude. Also there should be approximately 200 mVpp seen at either LO tank pin. The buffered LO output should yield 200–600 mVpp depending on the V_{CC} value used.

4. The R2 resistor must be included or else the oscillator will latch.

5. This method has been proven effective up to 65 MHz using 3rd overtone crystals, but has proven unreliable at higher frequencies (usually using 5th and 7th overtone types). For higher frequency operation on a single channel, a signal can be injected into the local oscillator port. (See the "First Mixer and Oscillator" section.)

6. Component values: The R1 resistors should be 10 to 50 kΩ and are included in order to add some current and gain to the local oscillator. L1 should equal L2 in nominal value and a fixed value might be used but startup with different crystals might be degraded. R2 should be 300 to 1500 Ω. X1 should be 3rd overtone, series mode resonant (no load capacitance specified).
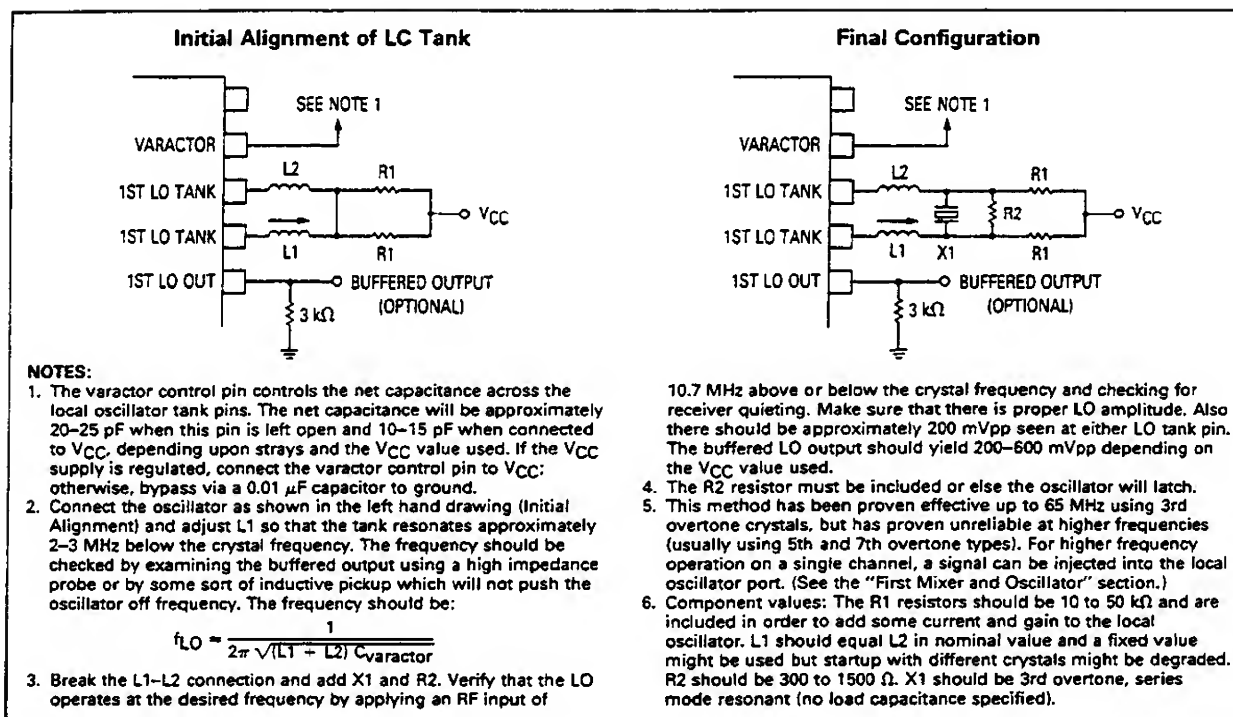
Figure 2. Running the MC3362/3 First Local Oscillator on a Single Channel Under Crystal Control

The open circuit conversion voltage gain of the first mixer is typically 24 dB, flat to 7 MHz. Internal rolloff is provided above 7 MHz to suppress RF and LO signals and spurious products sent on to the second mixer. The gain at 10.7 MHz is typically 18 dB. The output circuit is an emitter follower which is impedance-matched to 330 ohms to drive 10.7 MHz ceramic filters which typically have 330 ohm input and output impedances. For applications which require a high impedance crystal filters, impedance matching will likely need to be added at the first mixer's output to preserve the filter's response.

First Local Oscillator and Varactor Diodes

Associated with the first mixer is the first local oscillator (LO). It is a complete voltage controlled oscillator and only requires an external LC tank circuit (no external varactor diode). For multichannel applications, the oscillator includes varactor tuning and a buffered output suitable for interfacing to a PLL frequency synthesizer. This is the approach used in the receivers of Figures 10 and 11. The maximum oscillation frequency obtained has been approximately 190 MHz, achieved by injecting extra current into the oscillator. To inject current into the local oscillator, connect pull-up resistors of 10–50 kΩ from V_{CC} to each LO tank pin. The LO buffered output varies from 400 mVpp to 1100 mVpp with supply voltage and the output waveform appears best with $R_{pd} = 3$ kΩ, as shown in Figure 3.

There are internal varactor diodes which have capacitance which appears across the local oscillator tank pins. The internal capacitance can range from 10 to 25 pF

depending on the control voltage applied to the varactor control pin (MC3362 Pin 23, MC3363 Pin 27). The capacitance is maximum when the voltage applied is at the minimum (0.7 V) value. Applying voltages greater than V_{CC} and lower than 0.7 V to the varactor control pin can cause the oscillator to stop.

The first local oscillator can be crystal controlled to run on a single channel. The procedure of Figure 2 shows how to do this for applications through 65 MHz. The receiver of Figure 10 uses this approach.
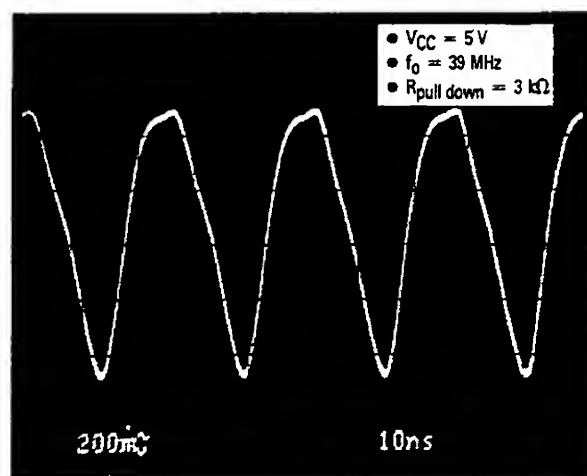
Figure 3. First Local Oscillator Buffered Output

A third application of the local oscillator is to drive it from an external source. This is recommended for applications from 75 MHz to 200 MHz and beyond which do not require PLL frequency synthesis. The inputs are differential and they must be driven using a wideband RF transformer or balun. The input voltage seen at either tank pin should be roughly 100 mVrms to ensure proper operation of the mixer and care should be taken so that any inductance present at the LO tank pins does not resonate with the internal varactor capacitance (a small valued resistor of 50–100 Ω should ensure this does not occur). Using this approach, no loss in mixer gain is seen until the RF and LO inputs are taken over 450 MHz. The RF and LO inputs should be run with a 10.7 MHz difference in frequency to accommodate the first IF bandwidth, so image frequency considerations (preselector filter quality) may limit the maximum RF input frequency to less than 450 MHz.

Second Mixer and Second Local Oscillator

After the 10.7 MHz IF signal is filtered using a ceramic filter, it is applied to the second mixer input. The second mixer is also doubly balanced to reduce spurious responses and typically is used to convert the 10.7 MHz IF down to 455 kHz for application to the limiting amplifier and detection circuitry. In the typical low cost application, the mixer is driven single-endedly from a ceramic filter, with one of the mixer inputs bypassed directly to the V_{CC} supply. The open circuit conversion voltage gain is typically 25 dB. For applications which require a high impedance crystal filter, impedance matching will likely need to be added at the second mixer input to preserve the filter response. The second mixer output is rolled off above 500 kHz, to reduce spurious response and idle noise.

The second local oscillator is a Colpitts type which is typically run under crystal control. The crystal used is specified for fundamental mode operation, calibrated for parallel resonance with a load capacitance of 30–40 pF. The typical waveform seen at the base is shown in Figure 4. The oscillator can be run at 10.240 MHz or 10.245 MHz, depending on the first local oscillator frequency desired.
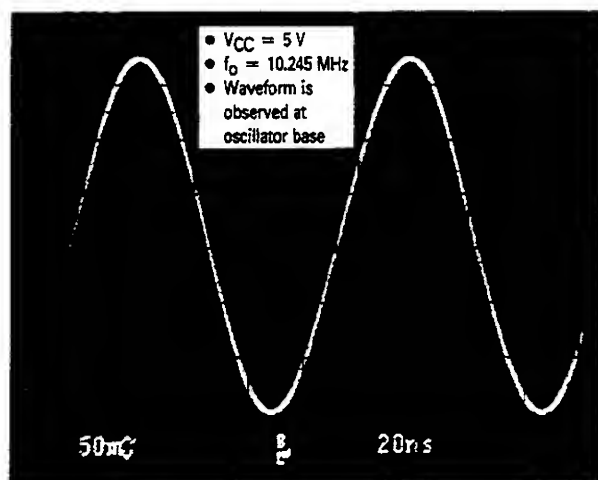
The MC3362 second local oscillator has a buffered output available which can be used to drive the reference frequency input of a PLL synthesizer or a prescaler. An external local oscillator signal can be injected into the local oscillator's base, with the emitter pin left open. The signal should be sinusoidal and should be approximately 300 mVpp to 500 mVpp in level.

The output admittance of the second mixer at 500 kHz is 1500 Ω in parallel with 50 pF; that is, $R_p = 1500$ Ω and $C_p = 50$ pF. The series equivalent impedance is $R_s = 1420$ Ω and $C_s = 1065$ pF. This impedance matches the typical input impedance of standard 455 kHz ceramic filters, which have 1500–2000 Ω typical input and output impedances.

Limiting IF Amplifier and Quadrature Detector

The 455 kHz IF signal is applied to the limiting IF amplifier, where it is amplified and limited before application to the quadrature detection circuitry. The limiting IF amplifier input has an input impedance of approximately 1.5 kΩ, which provides good power transfer from 1.5 kΩ ceramic filters. The limiting IF circuitry has 10 μV input sensitivity for -3 dB limiting, flat to 1 MHz. In order to preserve overall power supply current drain, the limiting IF and the receiver in general are not designed for wideband applications.

The coupling capacitor from limiter output to quadrature tank and detector input is provided internally and its value is 5 pF. The 455 kHz oscillator circuit is typically built around an LC tank circuit, with $C_p = 180$ pF, $L_p = 680$ μH. **Typical ceramic resonators can not be driven from the quadrature tank pin.** A waveform like that of Figure 5 should appear at the quadrature tank pin during periods of full receiver quieting and no modulation.

Meter Drive (RSSI)

The amplitude of the RF input signal at the appropriate frequency is monitored by meter drive circuitry. This circuitry detects the amount of limiting in the limiting IF amplifier and produces a linear change in current (nominally 0.1 μA) at the meter drive pin for each decibel of change in the RF input. The meter drive circuitry is fairly
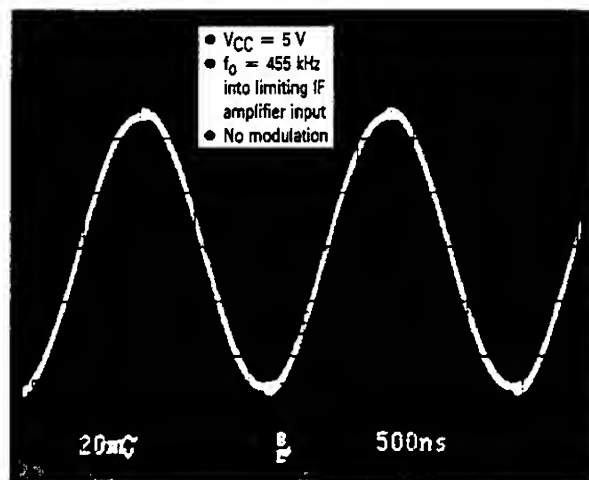

Figure 4. Second Local Oscillator Waveform

Figure 5. Quadrature Tank Pin Waveform Under Strong Received Signal Condition

linear for input signal levels over a 60 dB range. This output can be used as a meter drive or Received Signal Strength Indicator (RSSI) and needs to be bufffered. In order to provide a linear, wide ranging RSSI output voltage, three things must be accomplished:

1. The Meter Drive pin (MC3362 Pin 10, MC3363 Pin 12) should be clamped to within $V_{BE}/2$ (approximately 300 mV) of the MC3362/3 supply voltage, or loading of the Meter Drive's current source will occur. **The carrier detect output is disabled (high output) when the Meter Drive pin is clamped in this manner.** There are diodes present at the Meter Drive pin which can interfere with the Meter Drive. (See Figure 6 for a schematic representation.) With these diodes present the voltage swing possible at the Meter Drive pin is limited to a diode drop above and below the V_{CC} supply.

2. Some type of current to voltage conversion must take place. The RSSI output is typically 4 to 12 μA.

3. Negative feedback must be provided in the output buffer to counteract buffer amplifier gain variations. Some method of output level adjustment may be desirable.
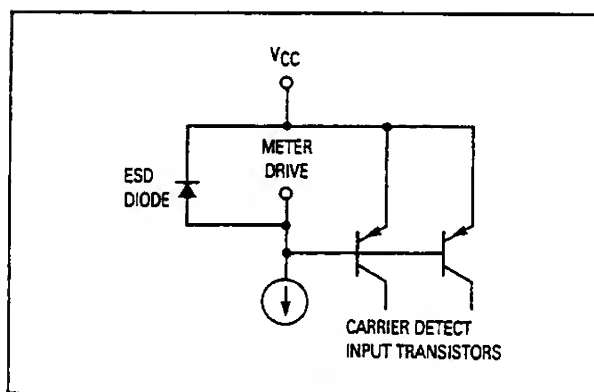

Figure 6. Schematic Representation of Meter Drive "Parasitic Circuits"

Carrier Detect

Another configuration for the meter drive and carrier detect circuitry, is to program the carrier detect output using a resistor from the meter drive pin to the V_{CC} supply. The carrier detect pin is an open collector output so a pull-up resistor is required. The carrier detect is active low, meaning that an RF input above the programmed trip level will yield a low output (<0.1 V) at the carrier detect pin. When the RF input is below the trip level (or is detuned) the carrier detect pin will be at the supply voltage. The trip level is set by the resistor value used between the meter drive pin and supply. A resistor of 130 kΩ sets the trip level to approximately -110 dBm at the first mixer's input, which is roughly the 12 dB SINAD point of the receivers with no external RF amplification. It should be noted that the meter drive current will not have the same linear 0.1 μA/dB current-input level relationship as when the meter drive is buffered as discussed above, so an analog RSSI output is not really achievable when Carrier Detect is used.
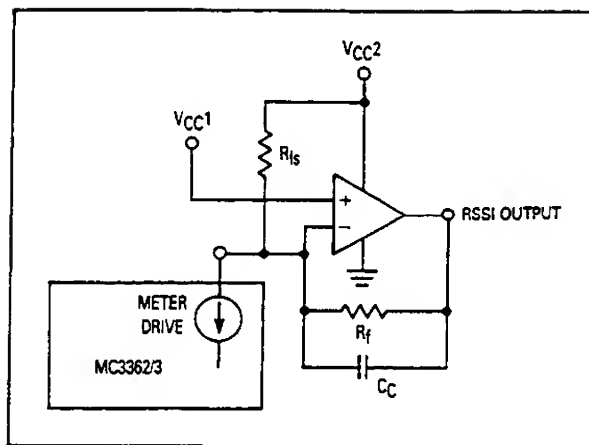

Figure 7. Sample RSSI Buffer

- Recommend MC33171 as the operational amplifier. The MC33171 is a low-power single supply single op amp with offset adjustment capability.
- $V_{CC}1$ = MC3363 supply (2 V to 7 V)
- V_{OUT} = $V_{CC}1$ + I_{meter} (R_f)
- $V_{CC}2$ = Op amp supply. Make this high enough to stay within the op amp's common mode input range — equal to $V_{CC}1$ + 2.2 V for the MC33171. This voltage also must be high enough to provide the maximum V_{OUT} desired.
- R_{ls} can be added to level shift the output, and is optional. The output voltage will be adjusted downward by a factor of ($V_{CC}1 - V_{CC}2$)(R_f/R_{ls}).
- Compensation capacitor C_C is added to ensure stability and will limit the circuit's response time.
- This circuit is not recommended for general purpose AM detection.

Muting (MC3363 only)

Audio muting can be provided in two ways. The carrier detect output can be DC coupled to the MC3363 muting op amp input (Pin 15) and the op amp output can serve to mute the audio. That is, the op amp output (Pin 19) serves as a switch to ground in the audio signal path. When the carrier level decreases below the carrier detect trip point, the carrier detect pin will go to V_{CC} and the op amp output will go into saturation, muting the audio. This yields a simple squelch with minimum external components and is shown in Figures 10 and 14.

Another way to mute the audio on MC3363 is to use the op amp as an active filter for detecting noise above the audio passband. The recovered audio is fed through the active filter, rectified, integrated and compared to a reference level. When the level rises above the reference, a squelch gate is triggered. The data slicing comparator on the MC3363 might be used as a squelch gate. This noise triggered squelch would be executed similarly to the squelch in MC3357/59/61 FM IF applications. (See the MC3359 data sheet for details.) This type of squelch frees the Meter Drive circuit to provide a linear output as noted under "Meter Drive (RSSI)" above.

Data Recovery

Both receivers contain a data slicing comparator which provides data shaping and limiting of frequency-shift keyed (FSK) serial data transmissions. The data slicer is a non-inverting type, with the negative input terminal biased internally to $V_{CC}/2$. Typically the data slicer is AC coupled to the recovered audio pin via a 0.01 μF to 0.1 μF capacitor. Larger coupling capacitors can cause distortion of the detected output and this is seen as negative slew rate limiting in Figures 8 and 9. A pull down resistor from the detector output pin to V_{EE} will reduce this effect if objectionable. The comparator output is an open collector so a pull-up resistor is required.

Comparator hysteresis is available by connecting the comparator output and input using a high-valued resistor. This helps maintain data integrity as the recovered audio becomes noisy, or for long bit strings of one polarity. Resistor values below 120 kΩ are not recommended as the comparator input signal will not be able to overcome the large hysteresis induced. Figure 8A shows data jitter resulting from noisy demodulated data signal. The improvement seen when hysteresis was added is shown in Figure 8B.

The maximum usable FSK data rate for any narrow-band FM system is typically 1200 baud subject to IF and quadrature bandwidth and adjacent channel spacing limitations. The approximate bandwidth required to generate or receive a frequency modulated signal is:

$BW \approx 2 (f_{mod} + f_{dev})$ kHz, where f_{mod} is the modulating frequency and f_{dev} is the frequency deviation.

This is known as Carson's Rule and is fairly accurate. Any modulating signal which exceeds the available IF bandwidth will be attenuated and/or distorted. For proper recovery of square waves including the leading and trailing edges approximately the 7th harmonic should be present. For a 1200 baud (600 Hz) square wave with f_{dev} = 3 kHz, f_{mod} = 4.2 kHz (7th harmonic of 600 Hz square wave), the bandwidth needed is: BW $\approx$ 2(4.2 + 3) kHz = 14.4 kHz = $\pm$7.2 kHz, which is acceptable in narrowband FM channels. Figures 9A and 9B show the effect of trying to pass a 9600 baud modulated carrier through a narrowband channel, with resulting degradation of recovered data.
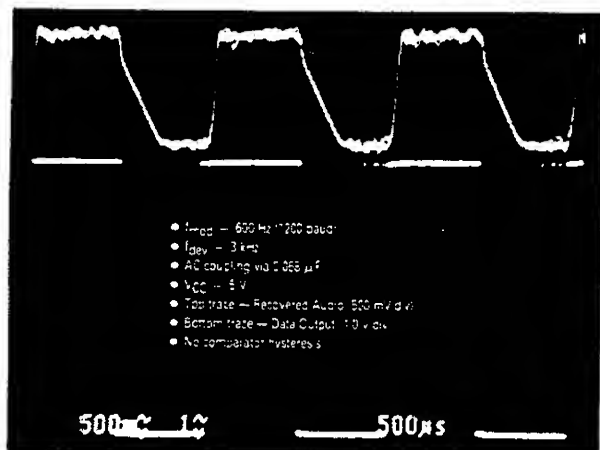

Figure 8A. Noisy Recovered Data Signal
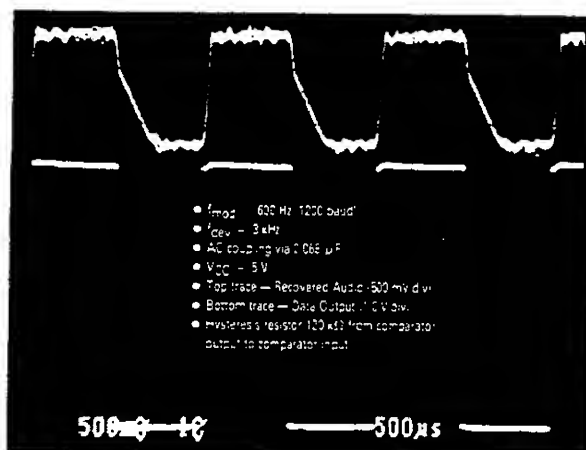Causes Data Jitter

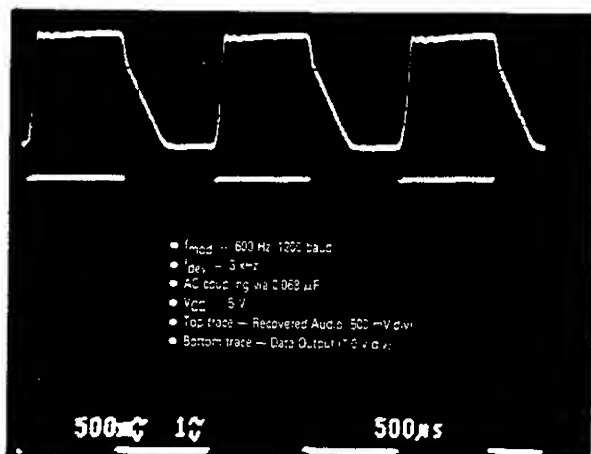Figure 8B. Improvement in Data Jitter
Through Addition of Hysteresis
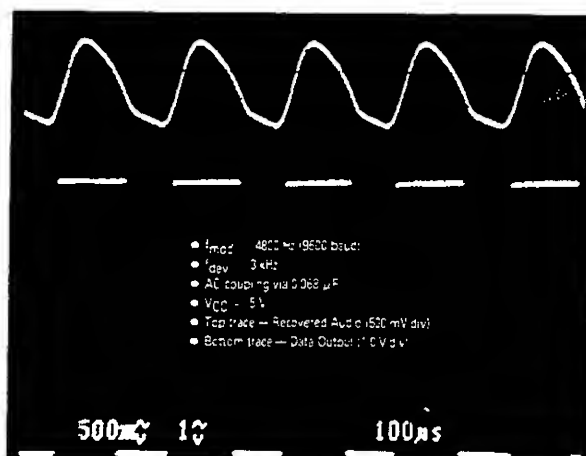

Figure 9A. FSK Data Recovery at 1200 Baud

Figure 9B. Distortion of Recovered Audio
with 9600 Baud Modulation

For narrowband RF modems where 300 baud is adequate, an audio frequency shift keyed (AFSK) approach is recommended. In this application two audio tones (for Logic "0" and Logic "1") are modulated onto an RF carrier and transmitted to the receiver, which reproduces the audio tone sequence. The audio tones can be generated at the transmitter and decoded after the receiver by the MC145442/3 single chip 300 baud modems.

BREADBOARDING

Do not attempt to build a high frequency radio circuit using a wirewrap or plug-in prototype board. While the MC3362 and the MC3363 are "tame" as high gain receivers go, high frequency layout techniques are critical to obtaining optimal receiver performance. This means (typically) a one- or two-sided copper clad board with adequate ground plane connected to V_{EE} potential. **It is also important that all V_{CC} interconnections are made using copper traces on the board. Do not use "free floating" point to point wiring for the V_{CC} interconnections!** In general, keep all lead lengths as short as possible, with an emphasis on minimizing the highest frequency pathlengths. Decoupling capacitors should be placed close to the IC. If these techniques are not followed then the
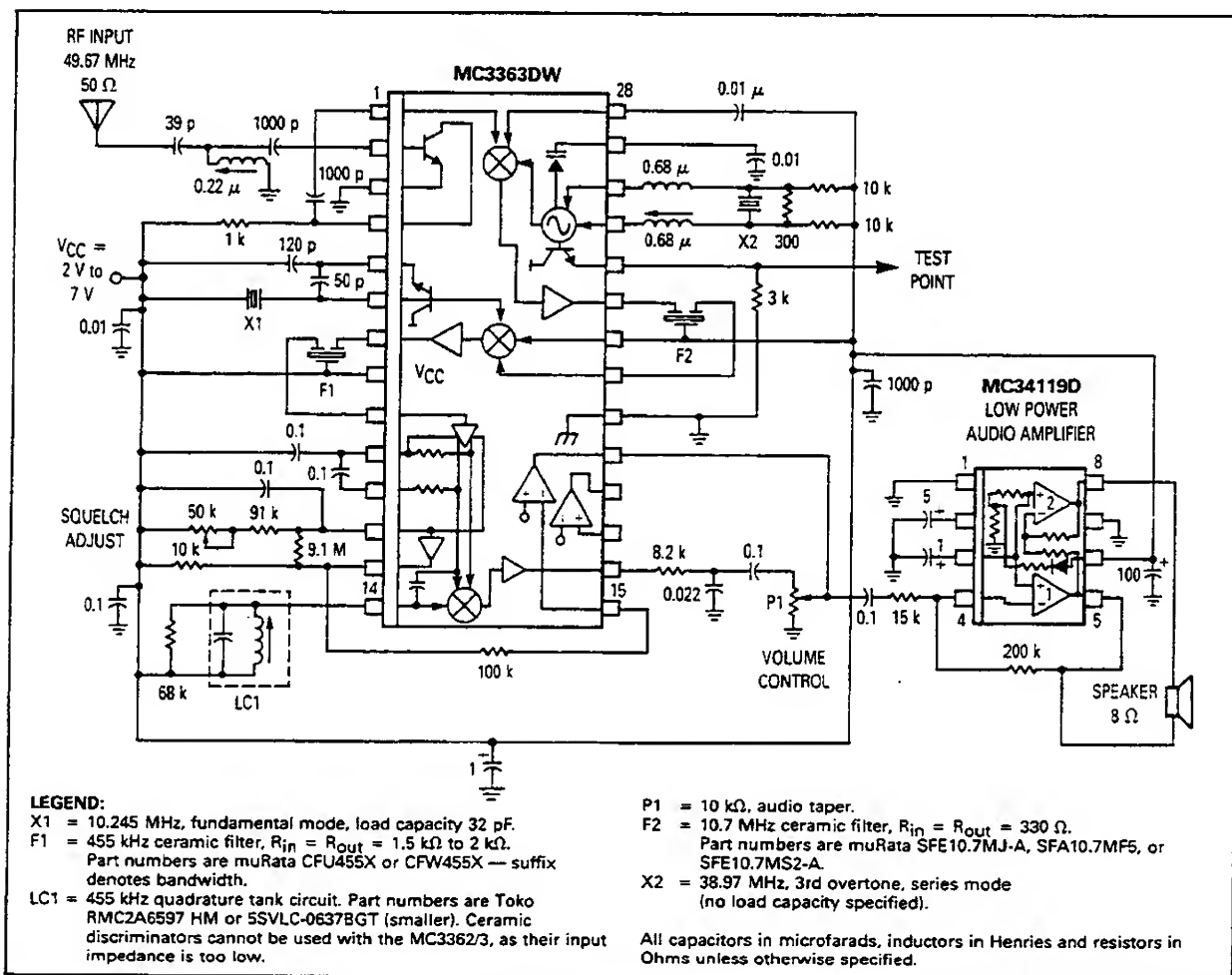
receiver sensitivity and noise quieting will suffer, and oscillations can occur.

APPLICATIONS CIRCUITS

Single Channel VHF FM Narrowband Receiver

The first application shown is of a complete single channel VHF receiver operating at 49.67 MHz. This application includes a suitable circuit for running the first local oscillator under crystal control on a single channel, which is particularly useful for dedicated remote control links and low cost two-way radios through 75 MHz. The circuit contains a simple carrier level based squelch circuit and audio amplification.

The 49.67 MHz receiver frequency is within the 49 MHz USA cordless telephone band. Radios built for this band may qualify under FCC Code of Federal Regulations Title 47, Part 15, for use by unlicensed operators. It is important to know the federal regulations concerning a particular frequency channel or band of channels before a receiver circuit is design (see the notes on **FEDERAL REGULATIONS, RECOMMENDED STANDARDS above**).

Figure 10 shows the complete receiver schematic. The LC network shown is used to match the input impedance

LEGEND:
X1 = 10.245 MHz, fundamental mode, load capacity 32 pF.
F1 = 455 kHz ceramic filter, $R_{in} = R_{out} = 1.5$ kΩ to 2 kΩ.
  Part numbers are muRata CFU455X or CFW455X — suffix denotes bandwidth.
LC1 = 455 kHz quadrature tank circuit. Part numbers are Toko RMC2A6597 HM or 5SVLC-0637BGT (smaller). Ceramic discriminators cannot be used with the MC3362/3, as their input impedance is too low.

P1 = 10 kΩ, audio taper.
F2 = 10.7 MHz ceramic filter, $R_{in} = R_{out} = 330$ Ω.
  Part numbers are muRata SFE10.7MJ-A, SFA10.7MF5, or SFE10.7MS2-A.
X2 = 38.97 MHz, 3rd overtone, series mode (no load capacity specified).

All capacitors in microfarads, inductors in Henries and resistors in Ohms unless otherwise specified.

Figure 10. Single Channel FM VHF Receiver at 49.67 MHz

of the RF amplifier to 50 Ω at this frequency. The amplifier collector load is a single resistor for simplicity and in order to enhance stability. The method of Figure 2 was used to develop the crystal controlled oscillator circuit at 38.97 MHz. The RC integrator rolls off the audio above 2 kHz in order to minimize unwanted noise output. This enhances receiver sensitivity and provides proper audio deemphasis. The receiver, without the audio amplifier, has 6.2 mA current drain at V_{CC} = 5 V for a total dissipation of 31 mW. Using a 455 kHz filter with a 6 dB bandwidth of ±10 kHz the receiver has a 12 dB SINAD point of 0.28 μV, modulation acceptance of 10.4 kHz and distortion below 1.2% with f_{mod} = 1 kHz and modulation deviation f_{dev} = 3 kHz. The maximum (S + N)/N ratio obtained is 60 dB.

The MC34119 audio amplifier adds 3 mA quiescent current drain at 5 V, can deliver 250 mW into an 8 Ω speaker

and has differential outputs which eliminate the need for the typical large audio coupling capacitor. It also has a chip disable input which provides muting and power conservation.

Ten Channel Frequency Synthesized Cordless Telephone Receiver

A demonstration receiver circuit has been built featuring the MC3362 and the MC145160 dual phase locked loop (DPLL). This receiver features frequency synthesis to cover the ten channels allocated in the USA for cordless telephone (CT) receivers in the 46 MHz (handset) and 49 MHz (base station) frequency ranges. The MC14516X series DPLL's feature two complete loops which control both the transmitter output and receiver first LO frequencies.
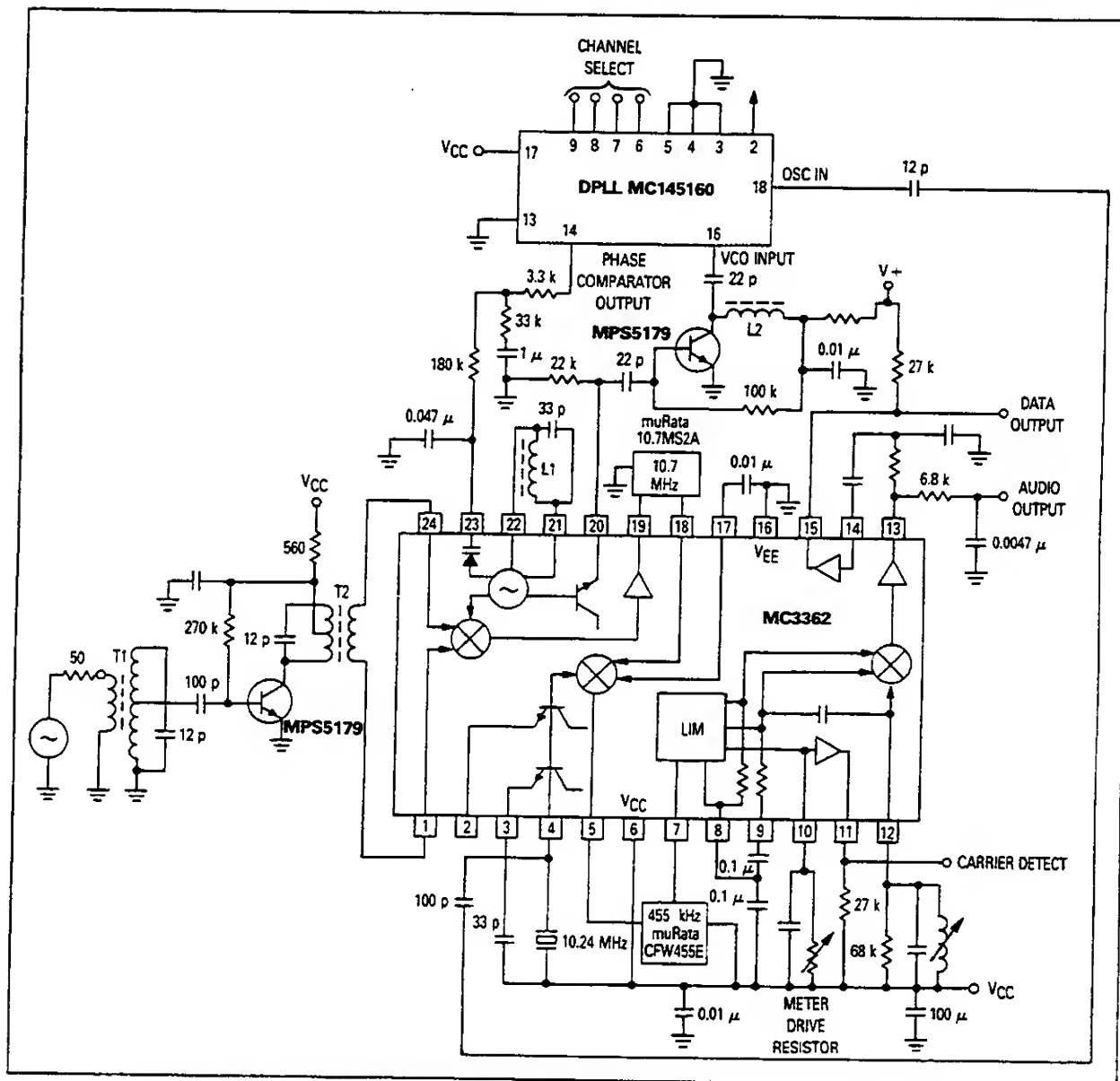
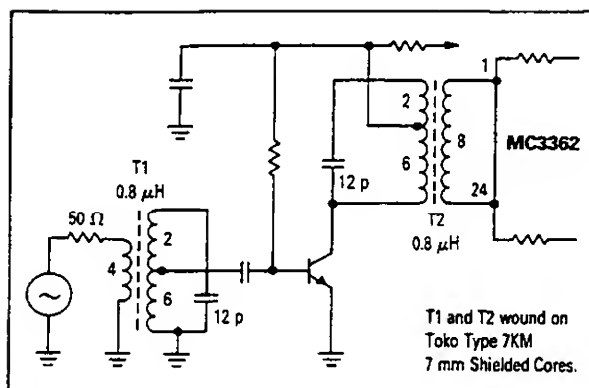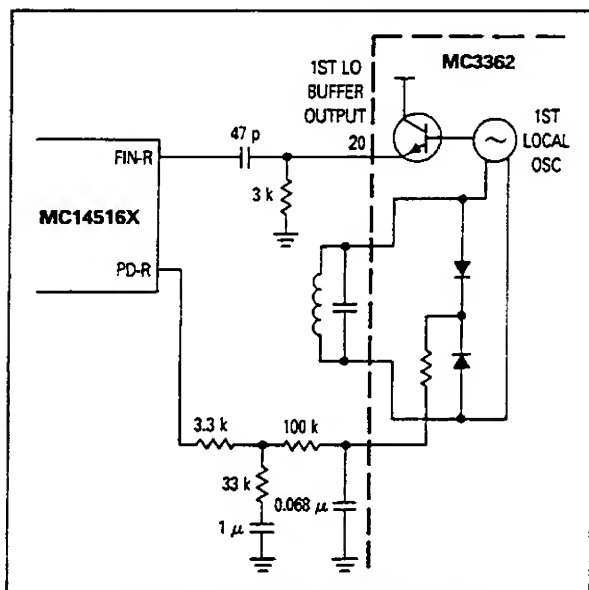Figure 11. Ten Channel Frequency Synthesized Receiver

Figure 12. Information on T1 and T2 of Figure 11

Figure 13. Simple Interface of MC3362/3 To DPLL MC14516X

Figure 11 shows the complete schematic diagram. A simple RF transistor amplifier is included to overcome antenna and RF preselector losses. The output of the VCO buffer is amplified by an external transistor amplifier so that the VCO signal strength is large enough to drive the receiver input pin (Fin-R) of the DPLL properly. Gain of the VCO is set at approximately 400 kHz using the LC values shown. The SB (Pin 3) of the MC145160 is grounded to disable the transmit loop to simplify development of the circuit and reduce power consumption. The DC voltage at the varactor control input of the MC3362 (Pin 23) is adjusted to $V_{CC}/2$. The system reference frequency of 10.240 MHz is generated in the MC3362 second LO and fed into the Osc-In (Pin 18) of the MC145160.

With a supply voltage of $V_{CC} = 3$ V and modulating signal $f_{mod} = 1$ kHz, $f_{dev} = 3$ kHz the receiver yields an input sensitivity of 0.6 μV for 20 dB noise quieting and 0.2 μV for 12 dB SINAD from a 50 Ω source. The

audio distortion is less than 3 percent. The minimum noise floor is less than 80 μV and the maximum $(S+N)/N$ ratio is 53 dB.

There is a simpler way to interface the MC3362/3 to the MC145160 DPLL as shown in Figure 13. The VCO signal (about 400 mVpp with $V_{CC} = 3$ V using a pull-down resistor of 3 kΩ from the MC3362 Pin 20 to V_{EE}) is fed directly into the Fin-R input (Pin 16) of the MC145160. With this configuration, the noise floor is raised to 245 μV, 10 dB higher than the circuit of Figure 11.

256 Channel Frequency Synthesized Two Meter Amateur Band Receiver

A more traditional PLL frequency synthesizer approach is needed to provide frequency flexibility and to allow the MC3362/3 receivers to operate in the VHF "high band" (130 MHz to 172 MHz). A receiver is shown which covers the entire Two Meter (referring to radio wavelength) amateur radio band from 144 MHz to 148 MHz in 256 channels spaced at 20 kHz. The complete receiver and PLL frequency synthesizer are shown in Figures 14 and 15. The receiver achieved the same specifications as the 49.67 MHz MC3363 receiver discussed above.

The MC3363 receiver was chosen because squelch and good sensitivity with minimum component count were desired. To obtain good operation of MC3363 VCO above 75 MHz, the first local oscillator must be running well. To ensure this, the V_{CC} supply voltage is kept above 3 V which increases the current in the local oscillator circuitry. Extra current is also injected into the local oscillator via pull-up resistors of 10 kΩ from each of the local oscillator tank pins to the V_{CC} supply. With the components of Figure 14, the receiver VCO had an average gain of 1.5 MHz/V.

The VCO output is amplified and fed into an MC12017 dual modulus prescaler which drives the input of the PLL frequency synthesizer. The MC145152-1 PLL frequency synthesizer was chosen for its ease of use and parallel input format. The MC33171 bipolar operational amplifier was chosen as the active integrator (loop filter) because of its low power drain, offset adjustment capability and ability to operate from a single supply voltage. The design equations and assumptions used to determine loop filter components are shown below. The MC145152-1 data sheet and other sources go into much more detail on PLL theory and performance.

Calculations of Loop Filter For VCO PLL Frequency Synthesis

Assumptions:

$f_O = 135.3$ MHz (local oscillator center frequency)

$f_s = 20$ kHz (channel spacing)

$f_b = 0.01$ f_s (loop bandwidth)

$f_{rc} = 20$ f_b (filter cutoff frequency)

$\xi = 0.707$ (loop damping factor)

$V_{DD} = 5$ V (PLL supply voltage)

$K_{VCO} = 9.4 \times 10^6$ rad/V (VCO gain, measured on MC3363 receiver)

$C1 = 0.1$ μF (active integrator component)

Results:

$f_b = 0.01\ f_s = 0.01\ (20\ \text{kHz}) = 200\ \text{Hz}$

$f_{rc} = 20\ f_b = 20\ (200) = 4\ \text{kHz}$

$K_\phi = V_{DD}\ /\ 2\pi = 0.796$ (phase detector gain)

$$w_n = \frac{2\pi\ f_b}{\{2\S^2 + 1 + [(2\S^2 + 1)^2 + 1]0.5\}0.5} = \left(\frac{1257}{2.06}\right) = 610\ \text{rad/sec}$$

$N_t = f_o\ /\ f_s = 135.3\ \text{MHz}\ /\ 20\ \text{kHz} = 6765$

$R_1 = K_\phi\ K_{VCO}\ /\ (C1\ w_n^2\ N_t) = 29.7\ \text{k}\Omega \approx 30\ \text{k}\Omega$

$R_2 = 2\ \S = (w_n\ C1) = 23.2\ \text{k}\Omega \approx 24\ \text{k}\Omega$

$C_C = 4 = (2\ R_1 f_{rc}) \approx 0.017\ \mu\text{F}$

With an 8 bit parallel input format several possible switch settings and resultant counter values and receiver frequencies are shown in Table 2 below (Note: $N_t = NP + A$, where $P = 64$ for the MC12017).

Table 2. PLL Frequency Synthesizer Switch Settings and Frequencies

Switches	N	P	A	N_t	f_{VCO} (MHz) $= N_t f_s$	f_{rx} (MHz) $= f_{VCO} + 10.7\ \text{MHz}$
00000000	104	64	0	6656	133.12	143.82
00000001	104	64	1	6657	133.32	143.84
01000000	105	64	0	6720	134.40	145.10
01111111	105	64	63	6783	135.66	146.36
10000000	106	64	0	6784	135.68	146.38
10001101	106	64	13	6797	135.94	146.64
10011100	106	64	28	6812	136.24	146.94
11010001	107	64	17	6865	137.30	148.00
11111111	107	64	63	6911	138.22	148.92

LEGEND:
X1 = 10.245 MHz, fundamental mode, load capacity 32 pF.
F1 = 455 kHz ceramic filter, $R_{in} \approx R_{out} = 1.5\ \text{k}\Omega$ to 2 kΩ. Part numbers are muRata CFU455X or CFW455X — suffix denotes bandwidth.
LC1 = 455 kHz quadrature tank circuit. Part numbers are Toko RMC2A 6597HM or 5SVLC-0637BGT (smaller). Ceramic discriminators cannot be used with the MC3362/3, as their input impedance is too low.

P1 = 10 kΩ, audio taper.
F2 = 10.7 MHz ceramic filter, $R_{in} = R_{out} = 330\ \Omega$. Part numbers are muRata SFE10.7MJ-A, SFA10.7MF5, or SFE10.7MS2-A.
L1 = 3 Turns #18 AWG, 0.25" diam., 0.125" spacing, air wound.
$V_{CC}2$ = 2–12 V, must be well decoupled from the V_{CC} source for the MC3363.

All capacitors in microfarads, inductors in Henries and resistors in Ohms unless otherwise specified.
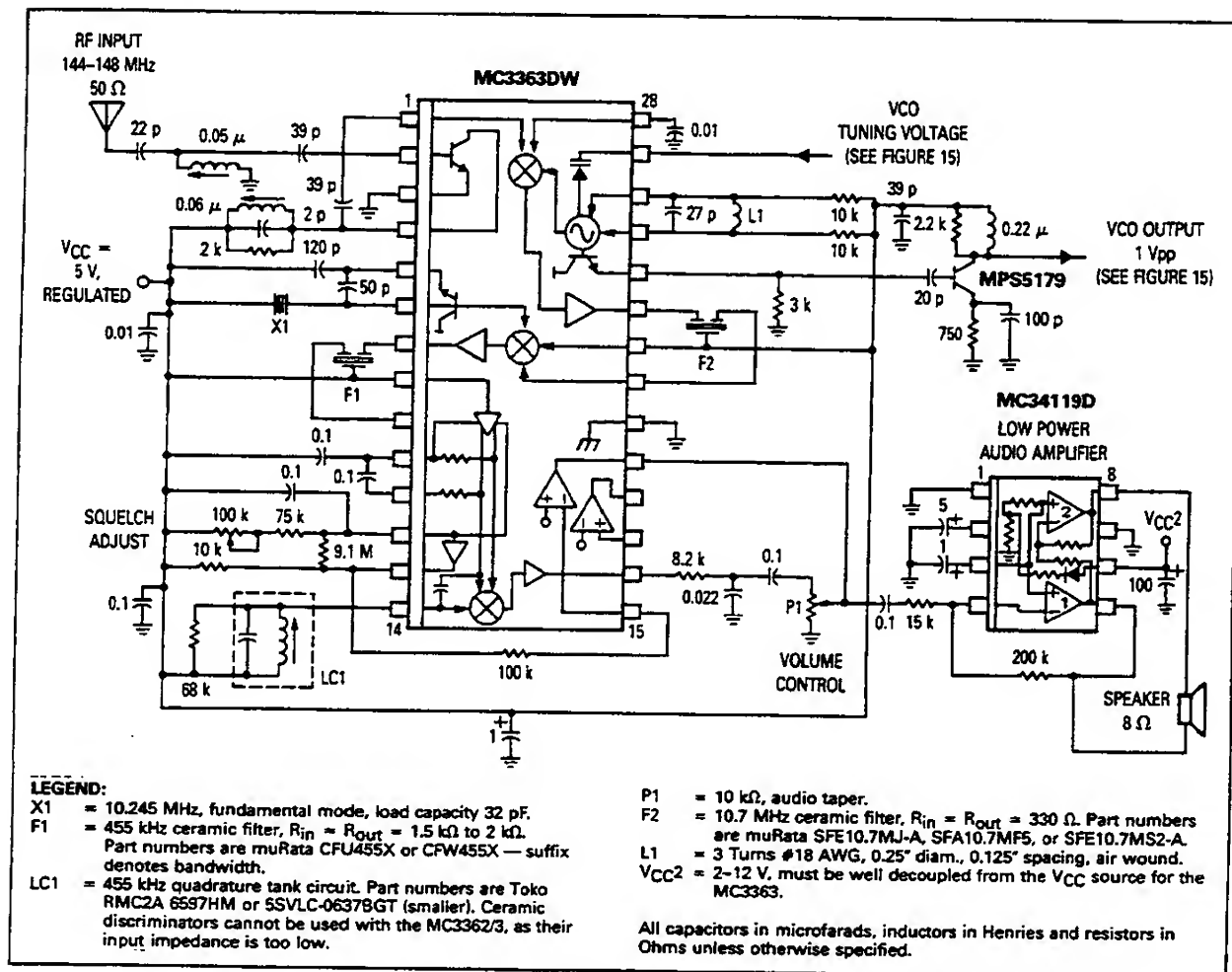
Figure 14. 2 Meter Frequency Synthesized FM Receiver

Single Chip Weatherband Receiver

An application of the MC3362 as a simple receiver tuned to the NOAA Weatherband (162.4 MHz to 162.55 MHz) is shown in Figure 16. The RF input is applied directly to the mixer input, using a simple "L network" to provide impedance matching of the mixer input to 50 Ω. The system sensitivity for 12 dB SINAD is 0.67 μV at the input from a 50 Ω source in this application, which is as good as most inexpensive weather cubes and the dual conversion design allows for excellent image protection to be provided.
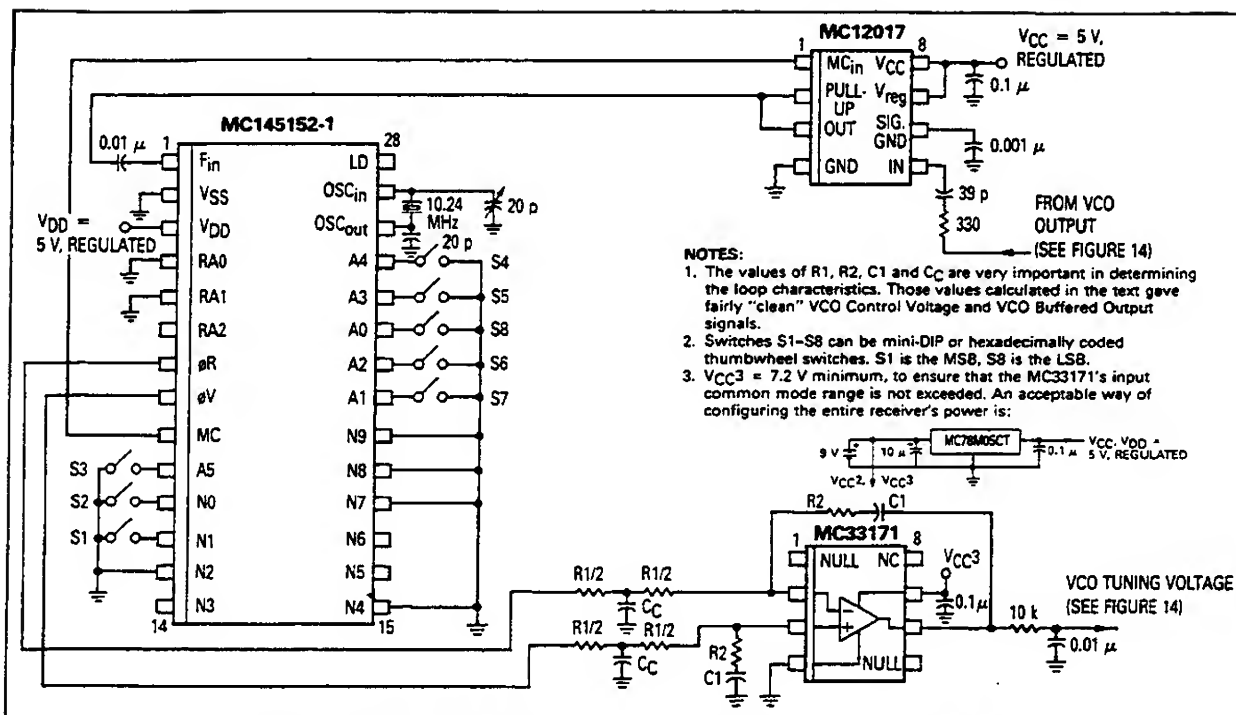
NOTES:
1. The values of R1, R2, C1 and C_C are very important in determining the loop characteristics. Those values calculated in the text gave fairly "clean" VCO Control Voltage and VCO Buffered Output signals.
2. Switches S1–S8 can be mini-DIP or hexadecimally coded thumbwheel switches. S1 is the MS8, S8 is the LS8.
3. $V_{CC}3 = 7.2$ V minimum, to ensure that the MC33171's input common mode range is not exceeded. An acceptable way of configuring the entire receiver's power is:

Figure 15. 256 Channel VCO Control Using PLL Frequency Synthesizer

NOTES:
1. Make V_{CC} connections along a substantial portion of copper plane. Do NOT use point to point wiring for V_{CC} interconnections!
2. V_{CC} (MC3362) = 2 V to 7 V, regulated. First local oscillator will drift if this supply is not regulated!
3. $V_{CC}2$ (MC34119) = 2 V to 12 V, must be well decoupled from the V_{CC} source for the MC3363.
4. L1 = 3 turns #18 AWG, .2″ dia., .05″ spacing, air wound.
5. Pins 1 and 24 are differential RF input, and are unmatched and used single-ended in this circuit. If single-ended input is used, be sure to bypass the unused pin.
6. All capacitors in microfarads, inductors in Henries and resistors in Ohms, unless otherwise specified.

Figure 16. MC3362 Application as a Tunable Weather Band Receiver

The first local oscillator is free-running in this application and the receiver is manually tunable over a range of ±1 MHz. The oscillator's frequency and tuning range are determined by the external tank circuit values chosen. Keep in mind that the internal varactor diodes add 10–25 pF of capacity across the tank pins, depending on the varactor control voltage applied.

This circuit is easily built to verify receiver characteristics on the lab bench, but as shown is not suited for mass production. The local oscillator temperature stability is not nearly adequate in this free-running configuration and microphonic pickup is difficult to avoid. Before a narrowband receiver is production-ready, the first local oscillator must be stable to within approximately ±100 Hz. The "First Mixer and Oscillator" section provides notes on driving the first mixer using an external oscillator signal above 50 MHz. The MC2833 FM transmitter IC might serve as the local oscillator source up to 200 MHz.

SUMMARY

The high degree of integration and MOSAIC process used in the MC3362/3 receivers give the radio designer new levels of space and power economy, while providing high performance and considerable design flexibility. The receivers shown and alternate configurations discussed should interest designers of cordless phones, VHF two way radios, remote control receivers, wireless data links and home security systems.

APPENDIX — DIRECTORY OF COMPONENT MANUFACTURERS

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Toko America Inc. 1250 Feehanville Drive Mount Prospect, IL 60056 **Distributor — Digikey** **Distributor — Inductor Supply**	(312) 297-0070 quadrature coils, crystal filters, coils, transformers (800) 344-4539 (800) 854-1881 (800) 472-8421 (California)
Coilcraft 1102 Silver Lake Road Cary, IL 60013	(312) 639-6400 coils
California Crystal Laboratories	(800) 333-9825 crystals
Comtec	(602) 526-4123 crystals
Fox Electronics	(813) 693-0099 crystals
International Crystals	(405) 236-3741 crystals
Standard Crystal Corporation	(818) 443-2121 crystals

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